



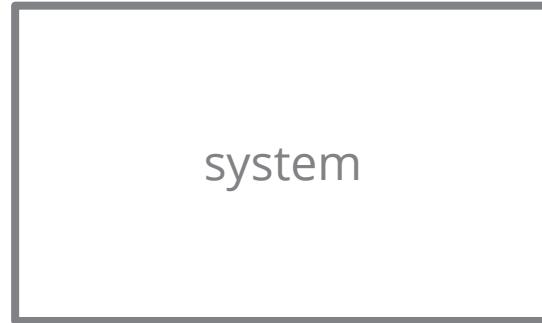
optimization algorithms by  
multi-gene genetic programming

Rogério Póvoa, Ph.D.

# optimization



inputs



system



outputs



constraints

# optimization

- telecommunication -



inputs  
 $(p_1, p_2, \dots, p_n)$



outputs  
covarage



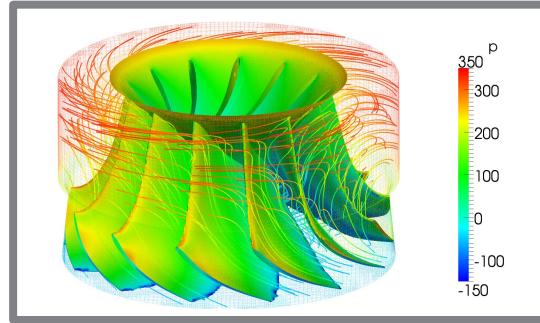
constraints

# antennas, boundaries, ...

optimization  
- design -



inputs  
models



outputs  
product quality

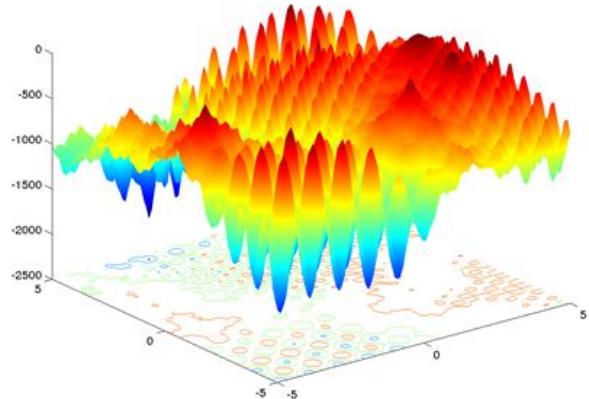


constraints  
physical quantities

deterministic

stochastic





stochastic

evolutionary computation

# THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION.

OR THE

PRESERVATION OF FAVOURED RACES IN THE STRUGGLE

FOR LIFE

apparat

By CHARLES DARWIN, M.A.

Charles Darwin



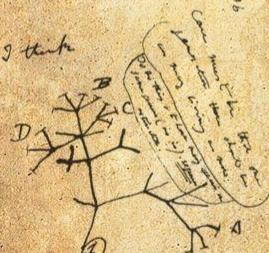
Gibbon

Orangutan

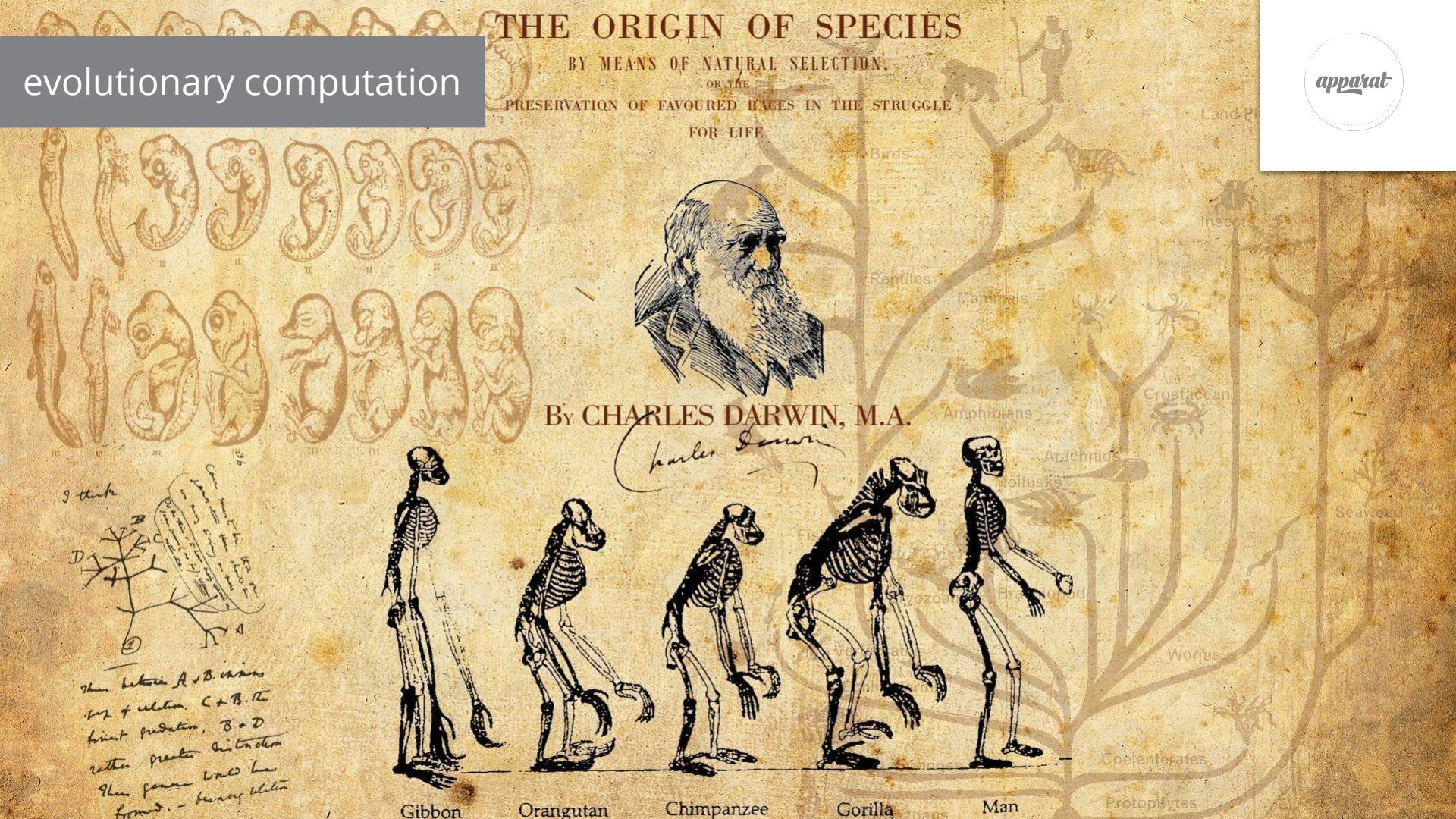
Chimpanzee

Gorilla

Man



I think  
there between A & B arises  
new & older C & D. The  
former generation, B & D  
rather greater antecedent  
than former will be  
thus formed. - having older

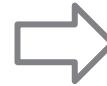
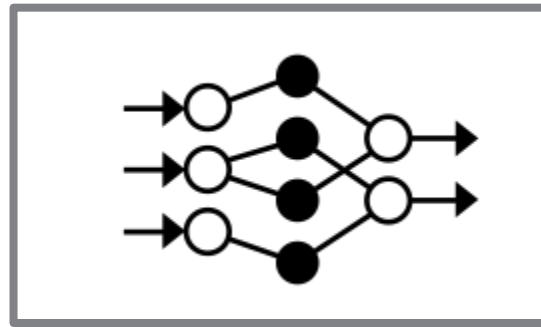
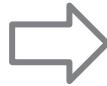


# evolutionary computation

- machine learning -

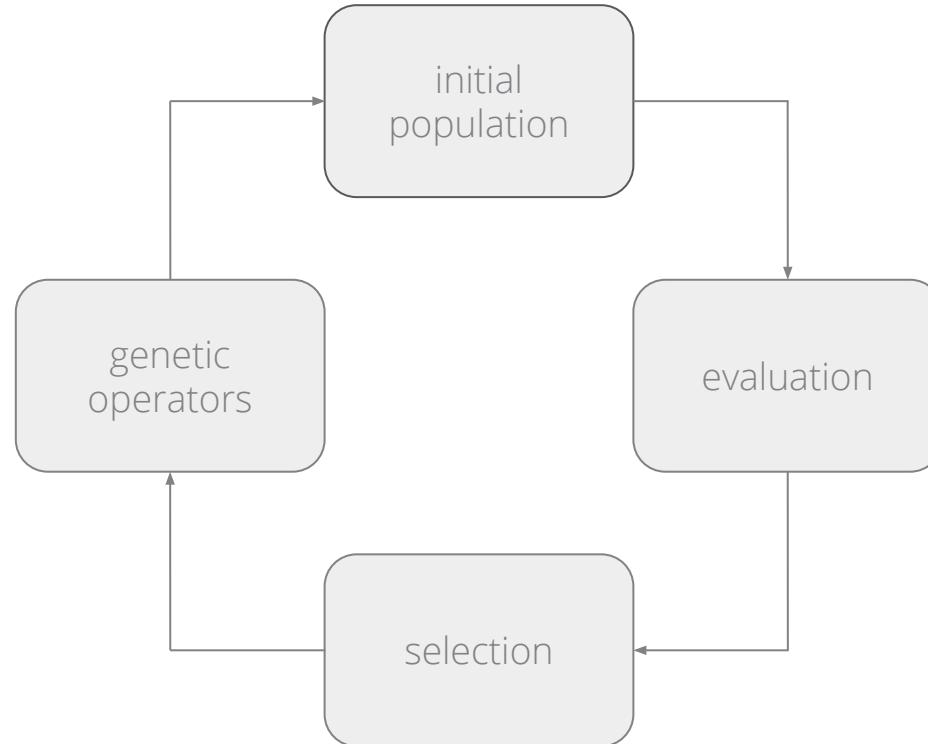


inputs  
models

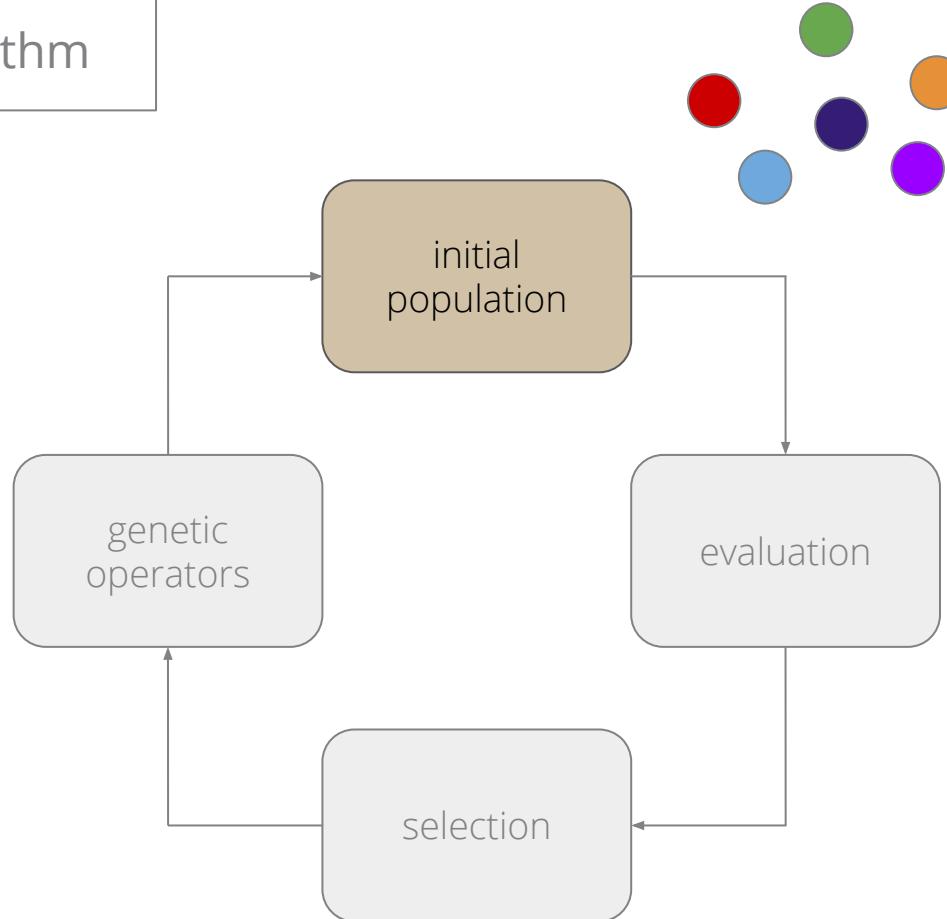


outputs  
performance

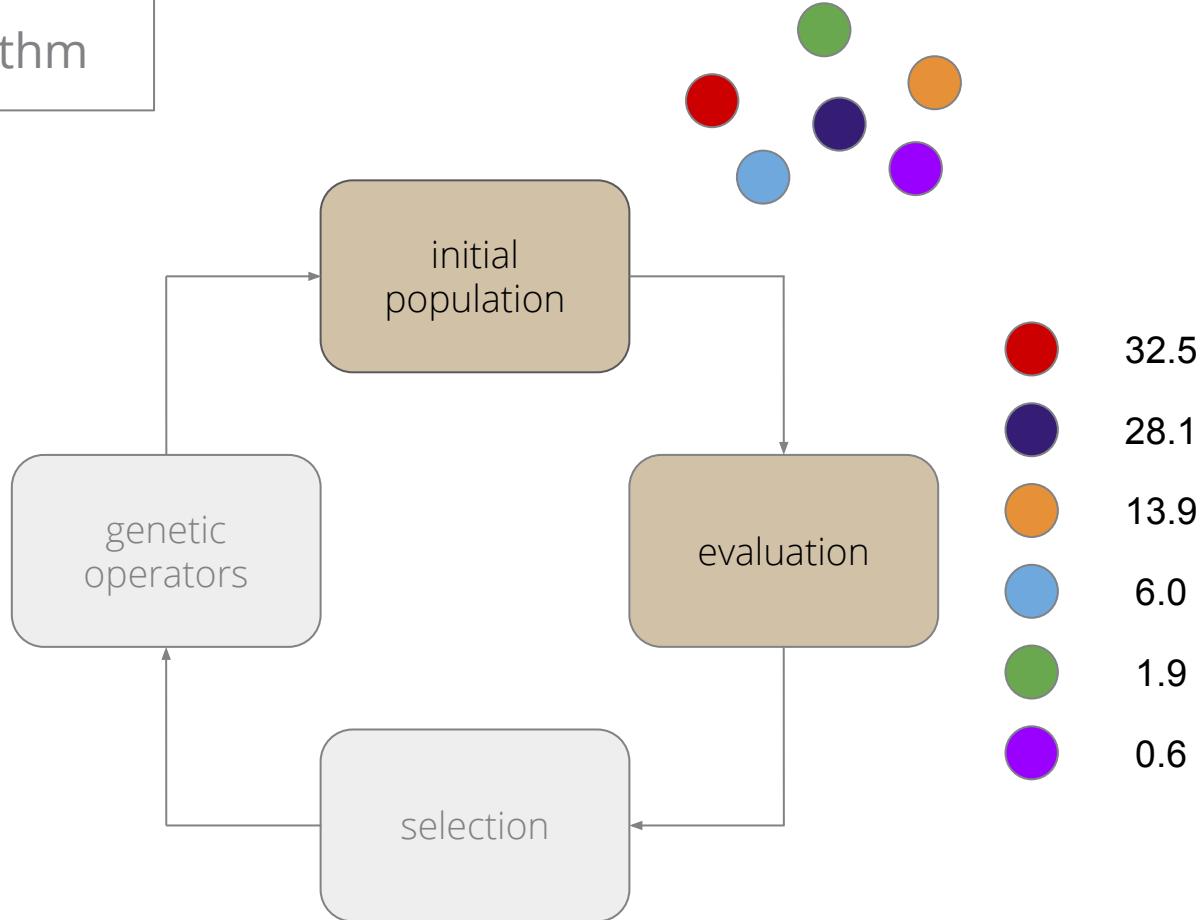
# evolutionary algorithm



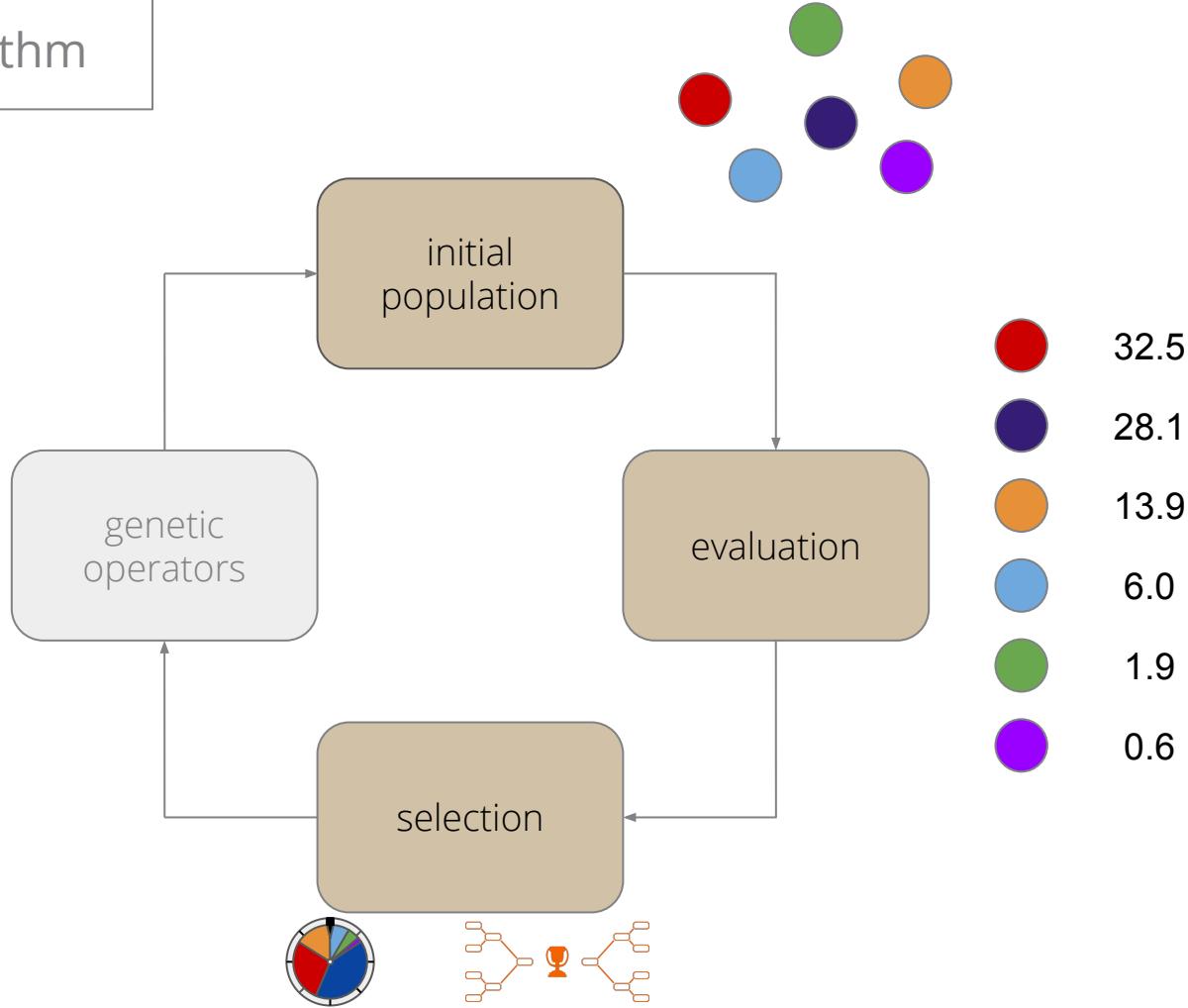
# evolutionary algorithm



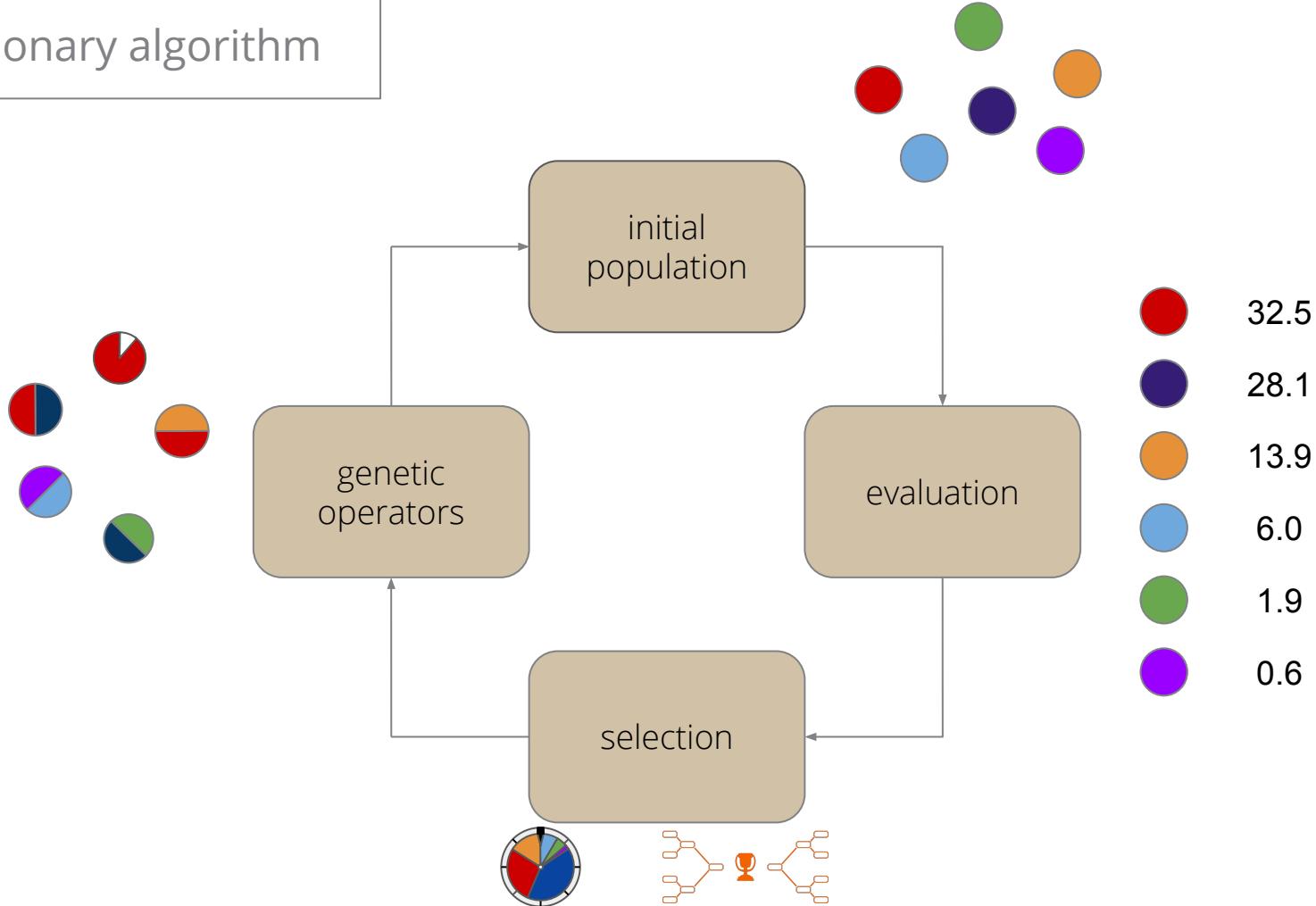
# evolutionary algorithm



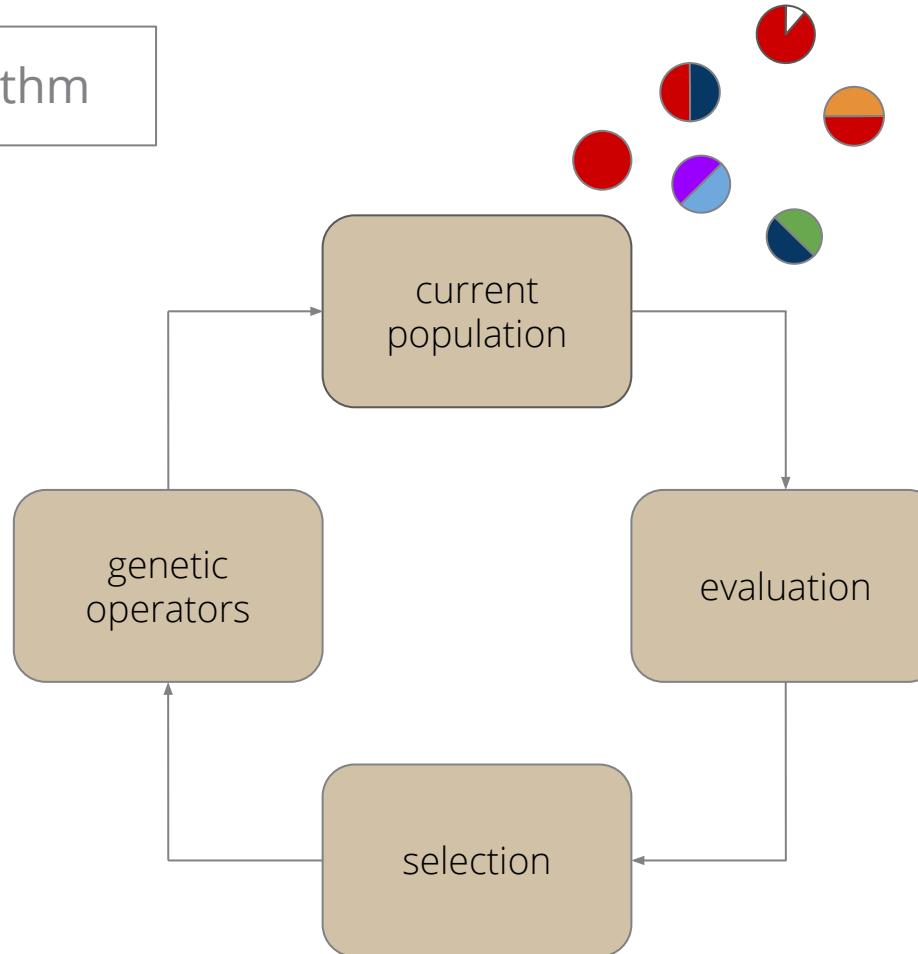
# evolutionary algorithm



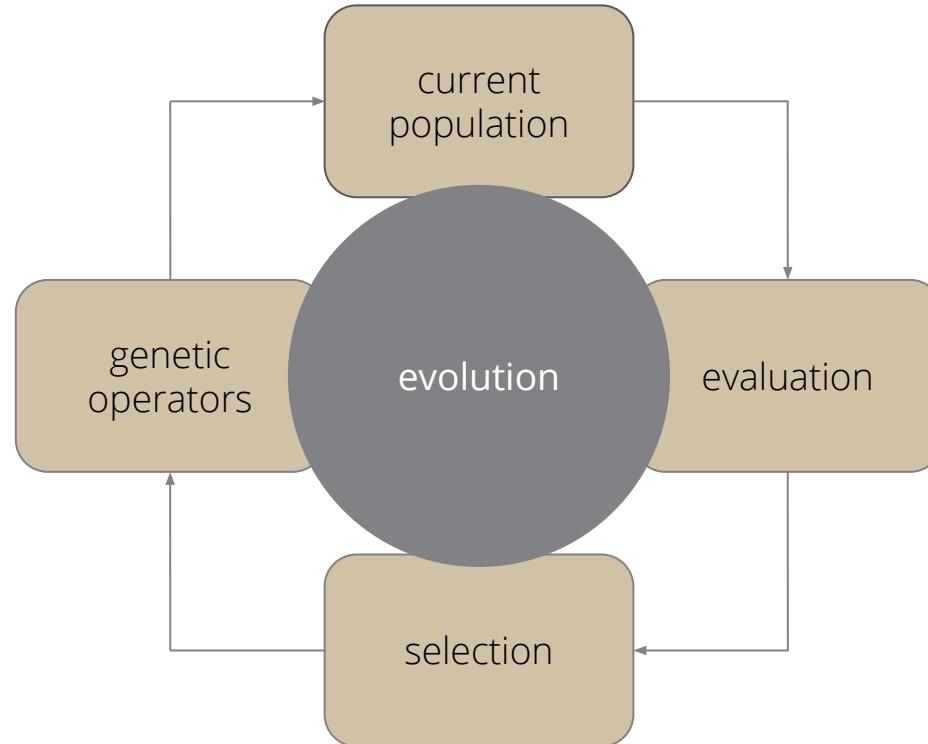
# evolutionary algorithm



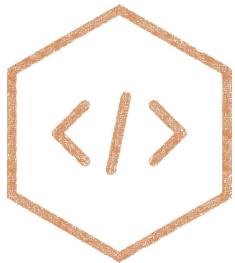
# evolutionary algorithm



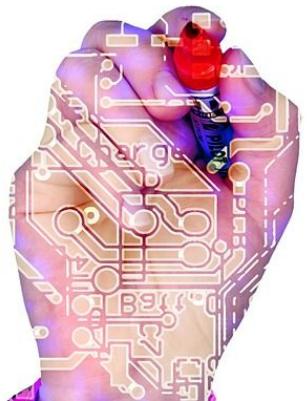
# evolutionary algorithm



# genetic programming (gp)

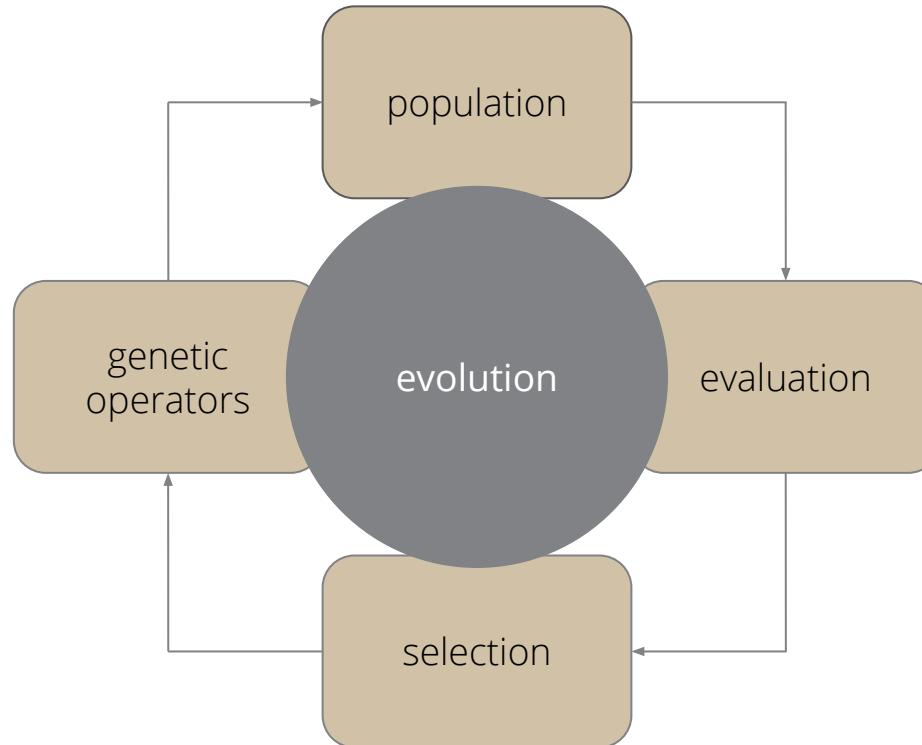


$f(x)$



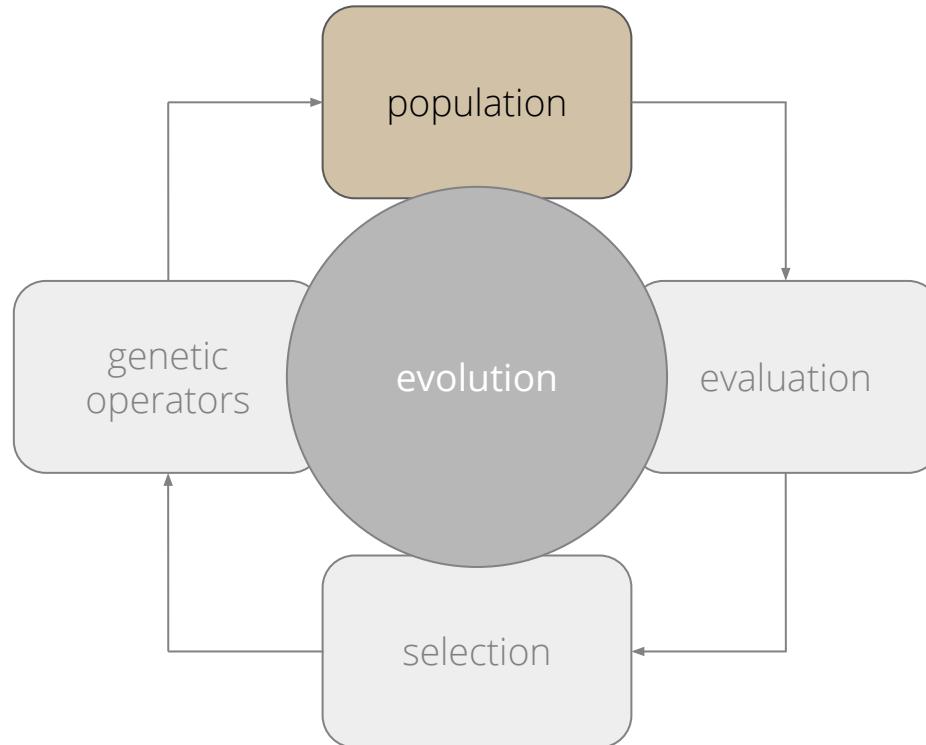
# evolutionary algorithm

- gp -



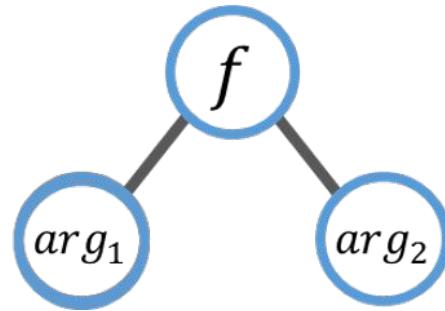
# evolutionary algorithm

- gp -

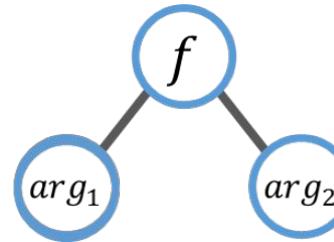


representation

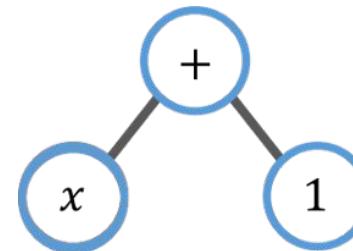
$(f \ arg_1 \ arg_2)$



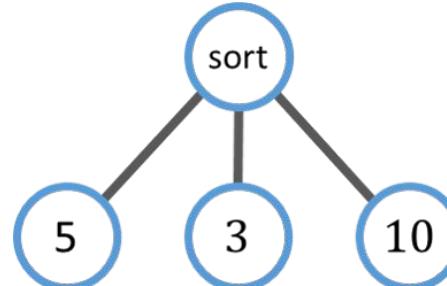
*( $f$   $arg_1$   $arg_2$ )*



*( $+ x 1$ )*

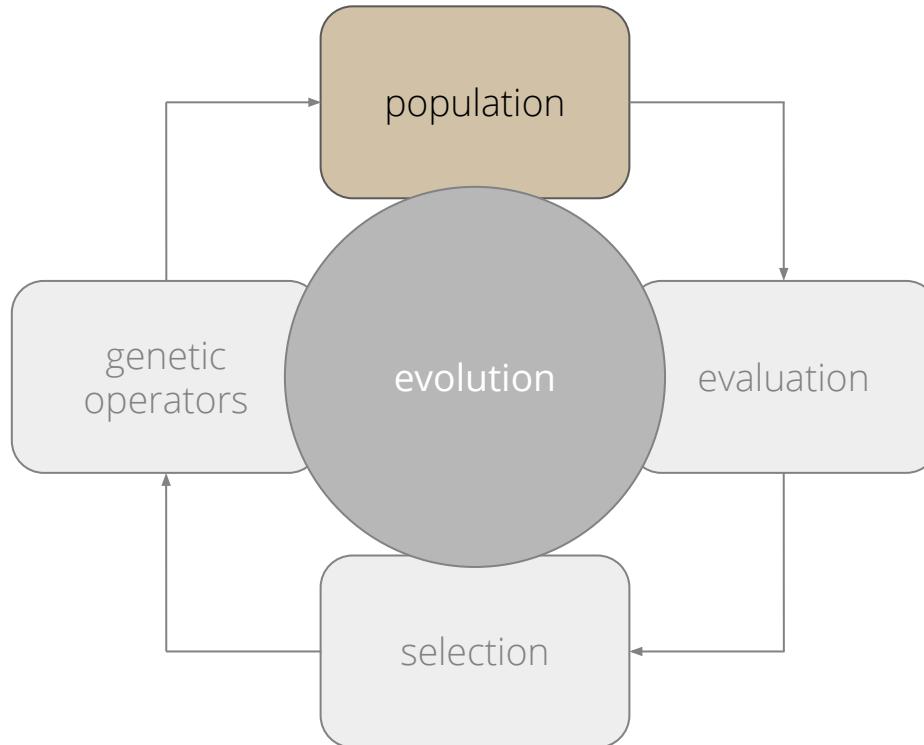


*( $sort$  5 3 10)*



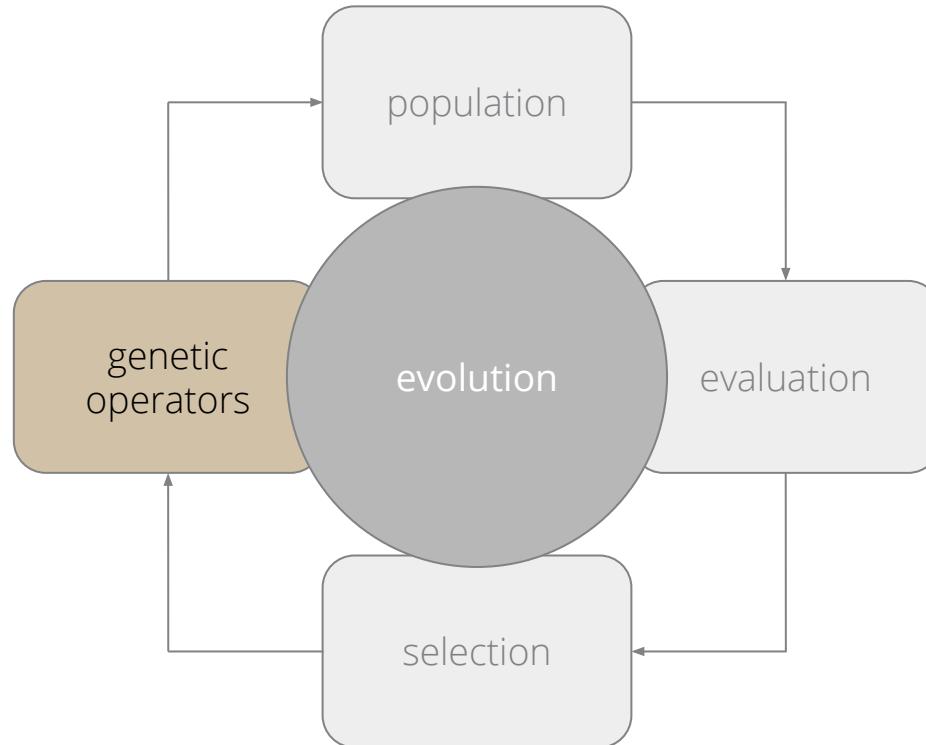
# evolutionary algorithm

- gp -



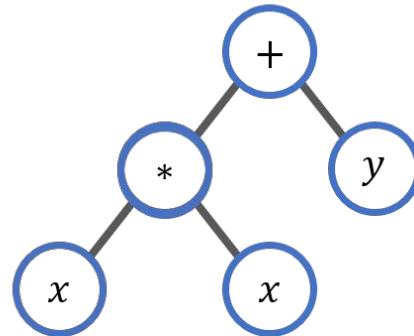
# evolutionary algorithm

- gp -

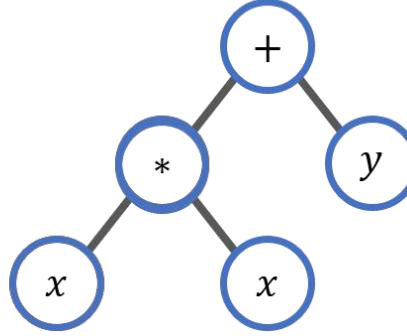


# direct reproduction

$$x^2 + y$$

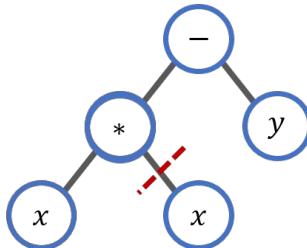


$$x^2 + y$$

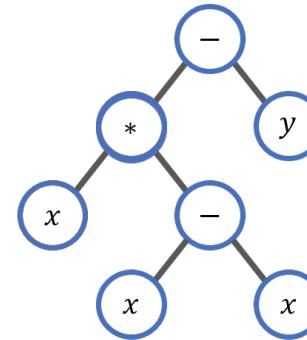


# crossover

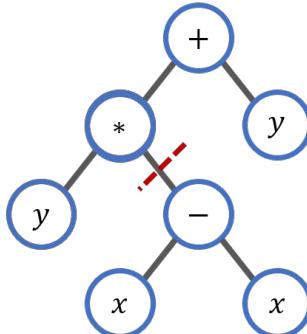
$$P_1 = x^2 - y$$



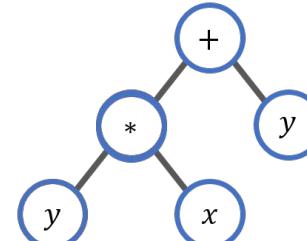
$$O_1 = x(x - x) - y$$



$$P_2 = y(x - x) + y$$

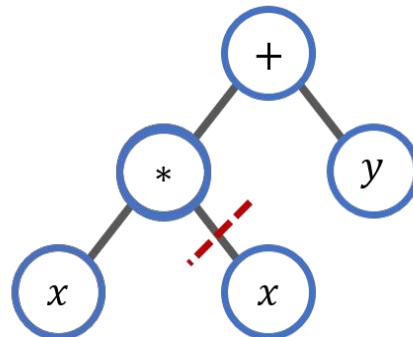


$$O_2 = yx + y$$

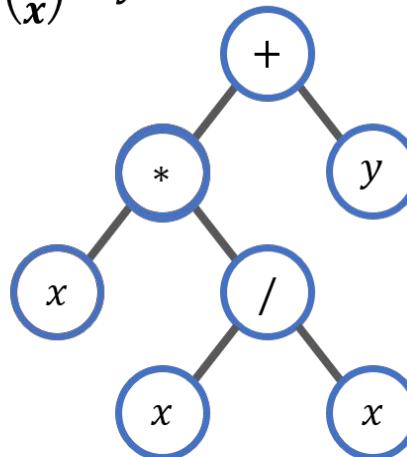


# mutation

$$x^2 + y$$



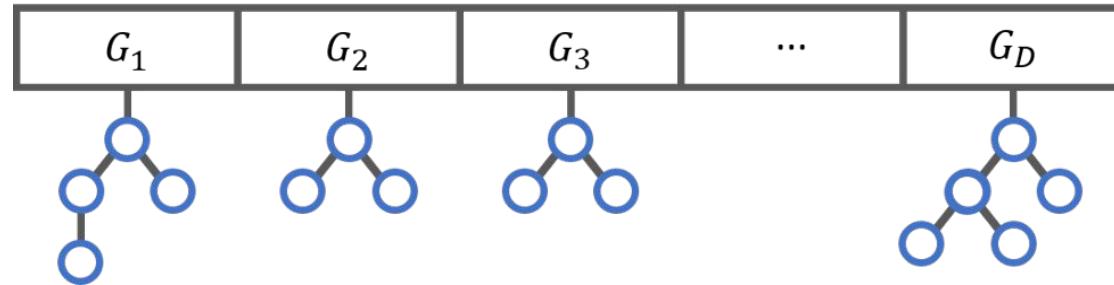
$$x\left(\frac{x}{x}\right) + y$$



optimization algorithms by  
multi-gene genetic programming

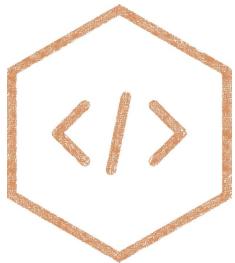
??

# multi-gene genetic programming

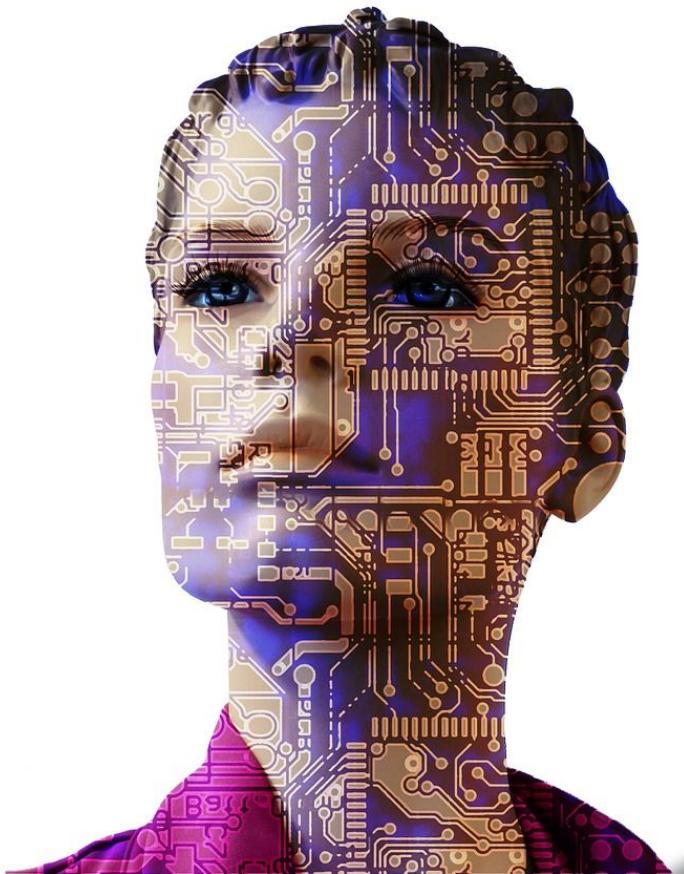
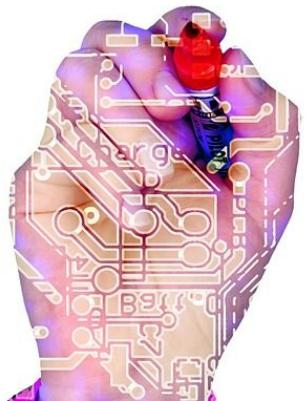


$$\hat{Y}_i = \beta_0 + \sum_{d=1}^D \beta_d G_d$$

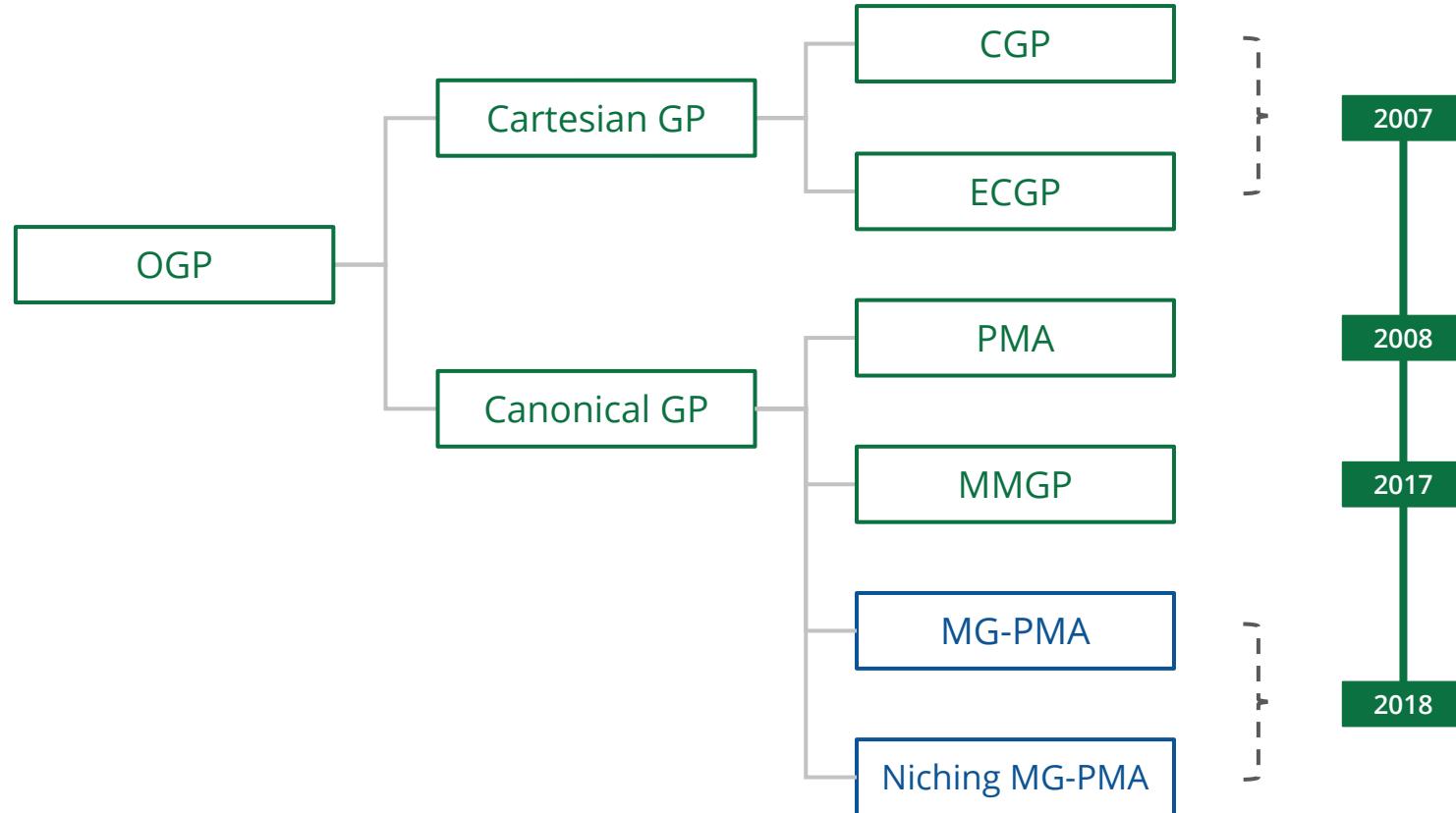
# genetic programming (gp)



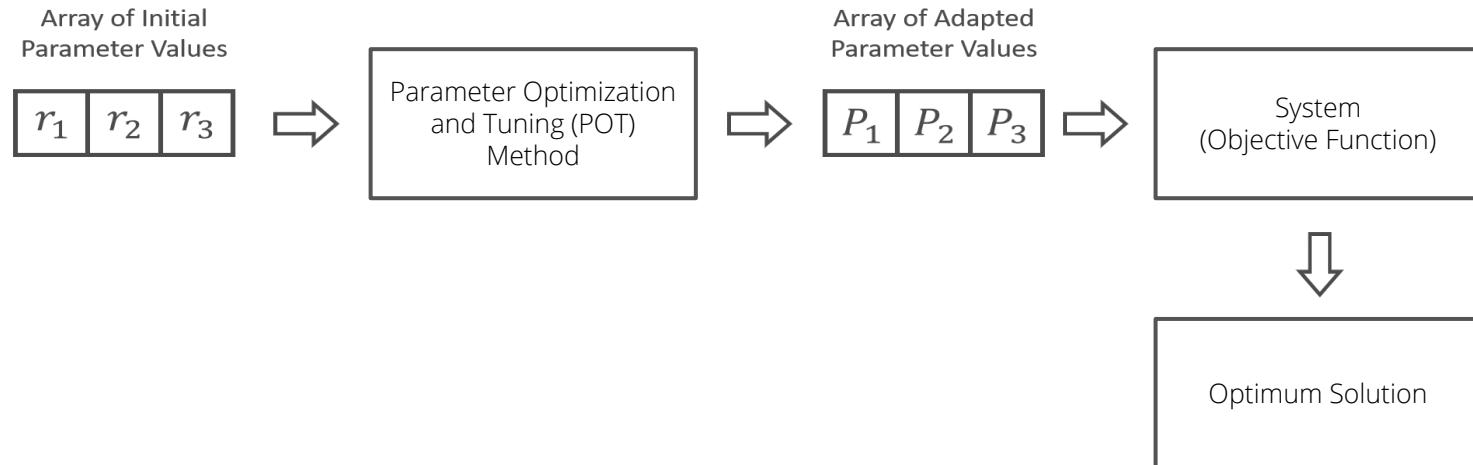
$f(x)$



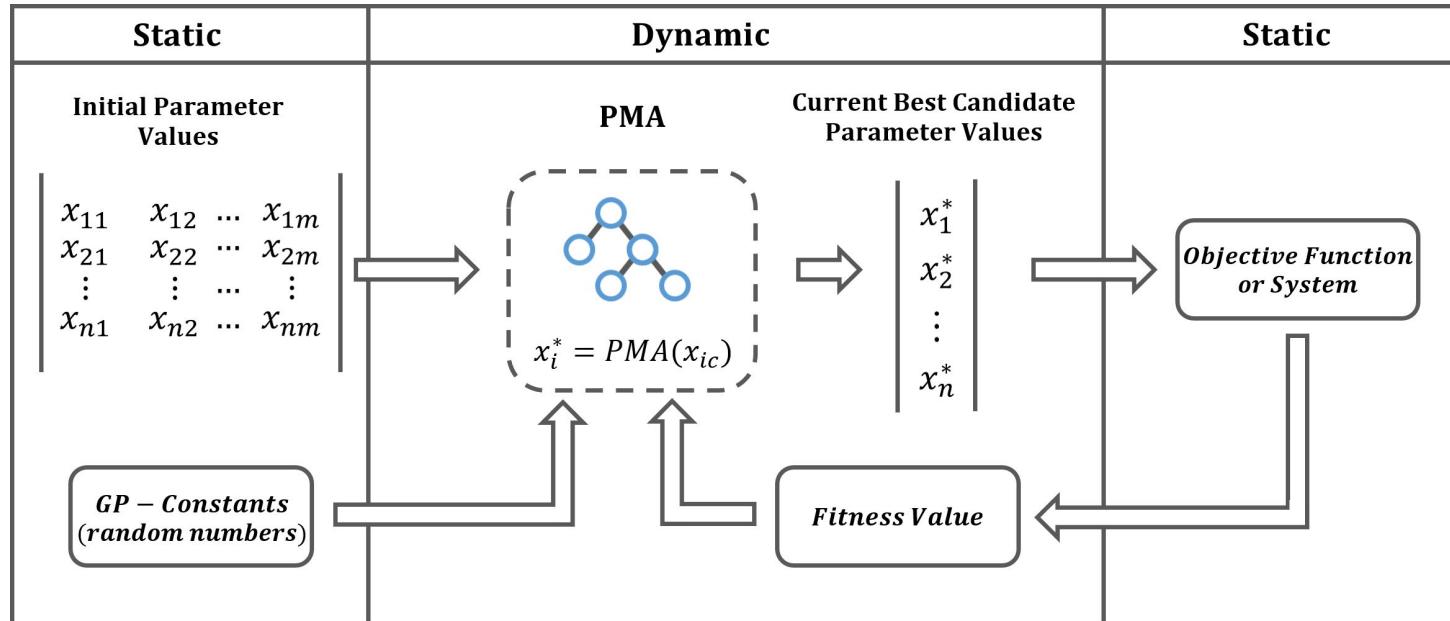
# optimization by genetic programming



# parameter mapping approach (PMA)



# parameter mapping approach (PMA)

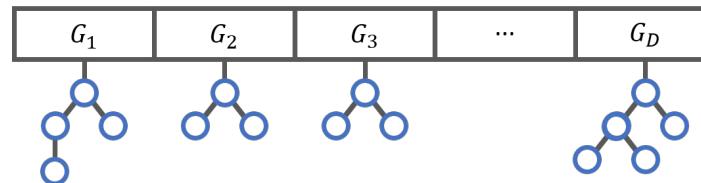
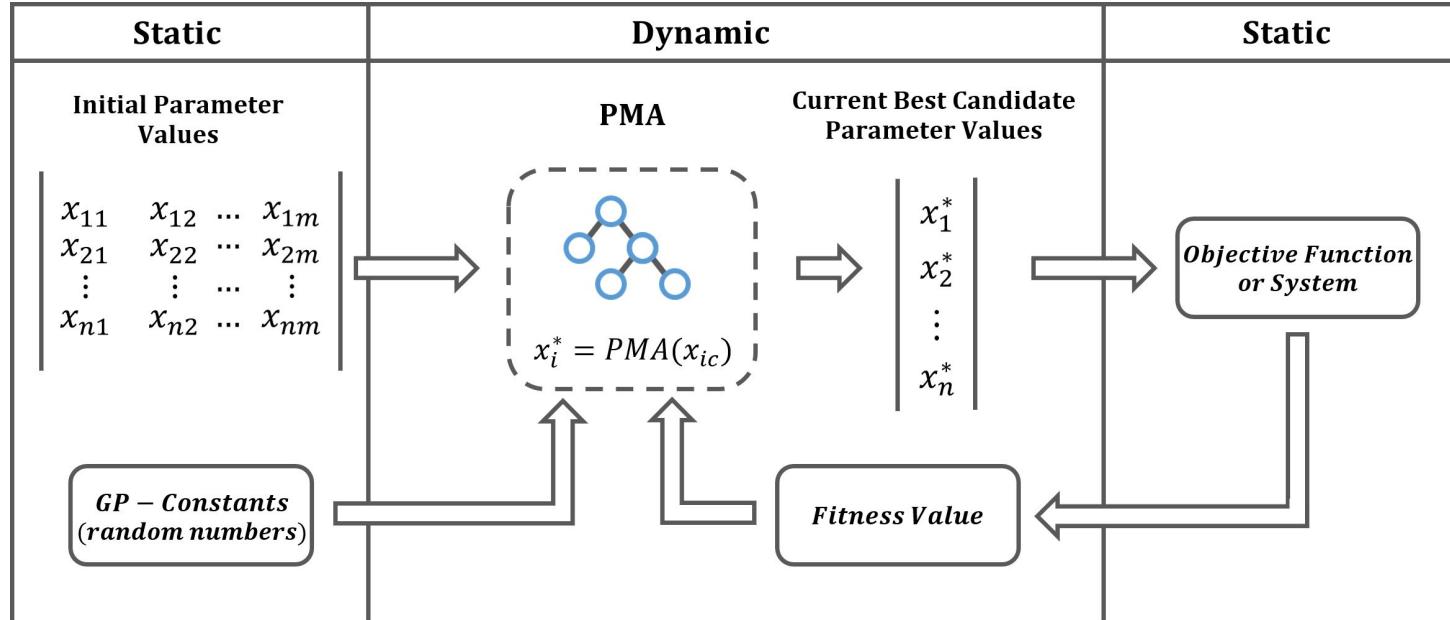


# parameter mapping approach (PMA)

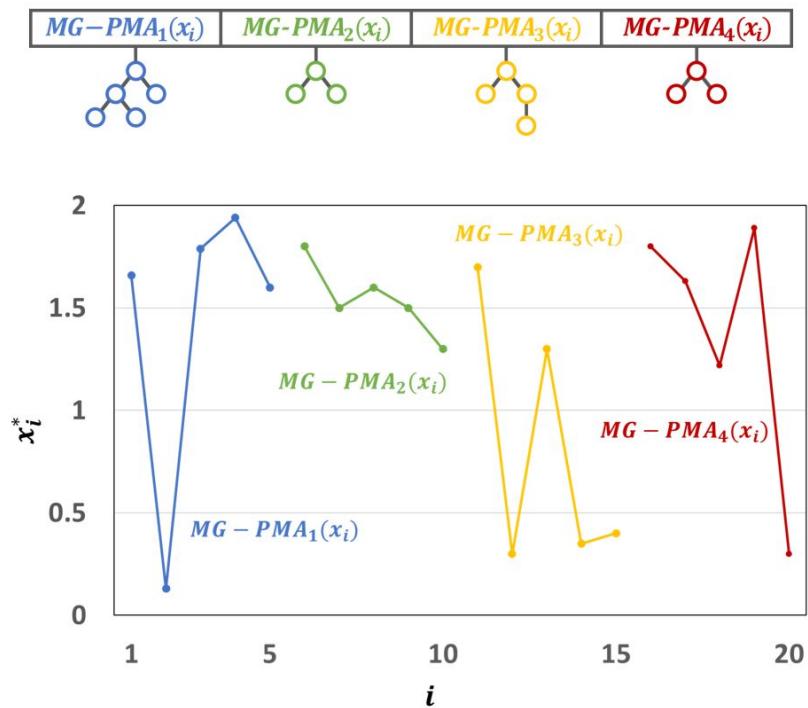
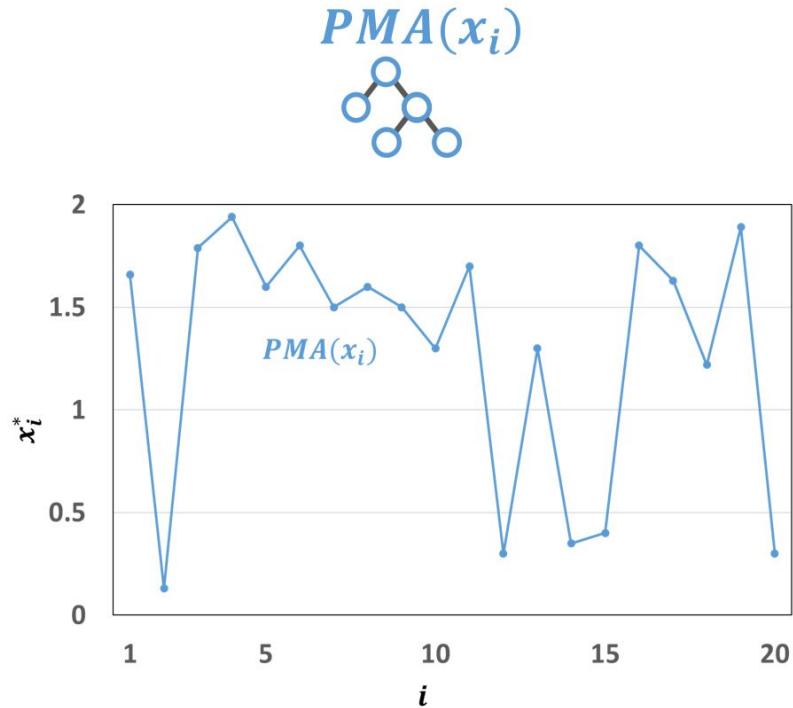


# multi-gene parameter

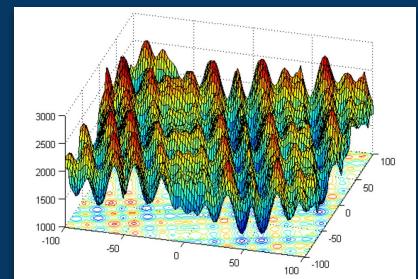
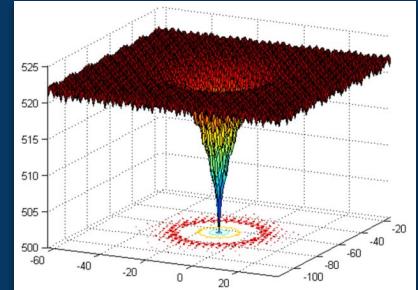
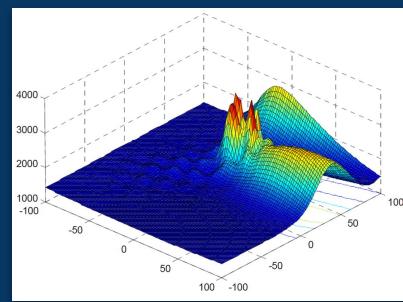
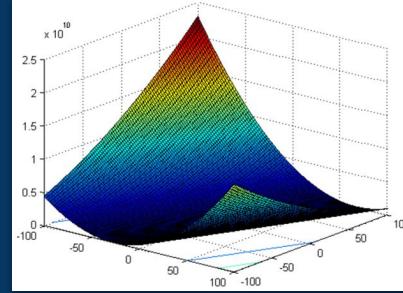
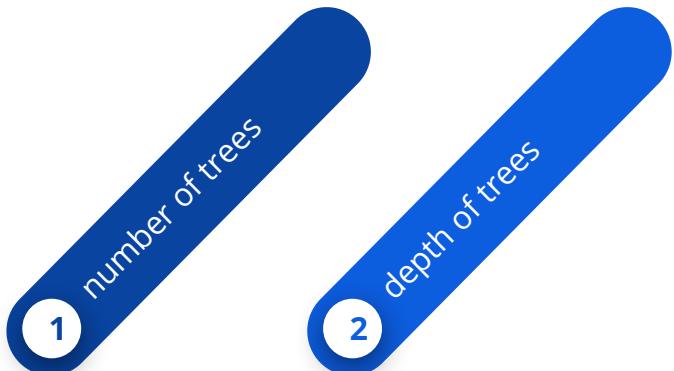
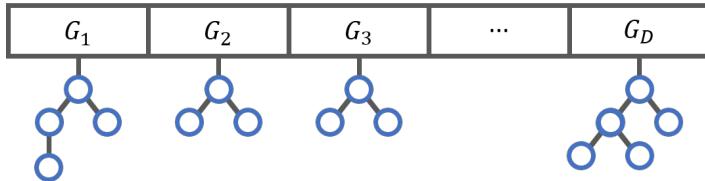
## mapping approach (MG-PMA)



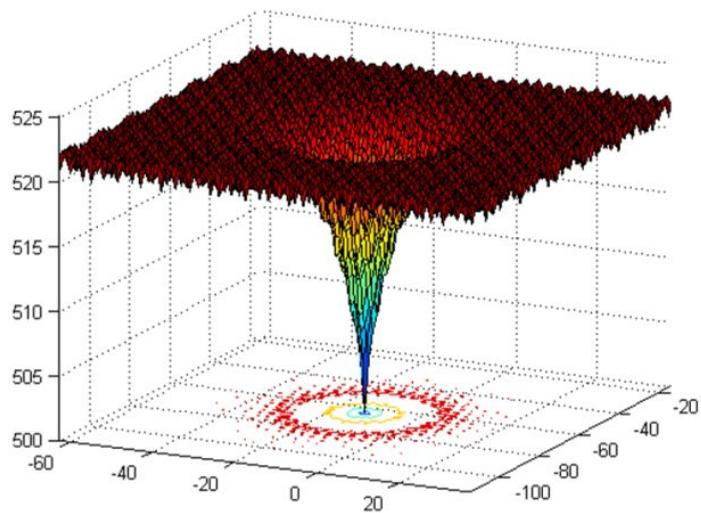
# multi-gene parameter mapping approach (MG-PMA)



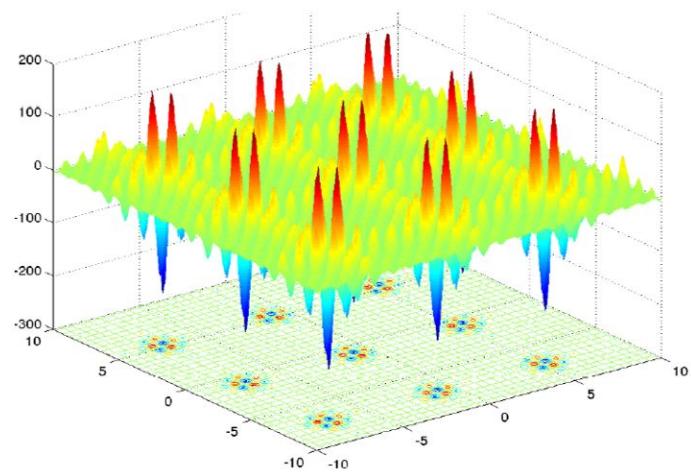
# multi-gene parameter mapping approach (MG-PMA)



## unimodal & multimodal



unimodal



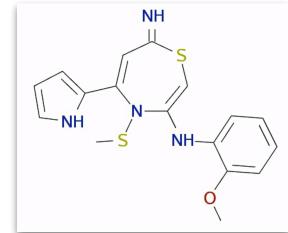
multimodal

# evolutionary computation

- drug molecule design -



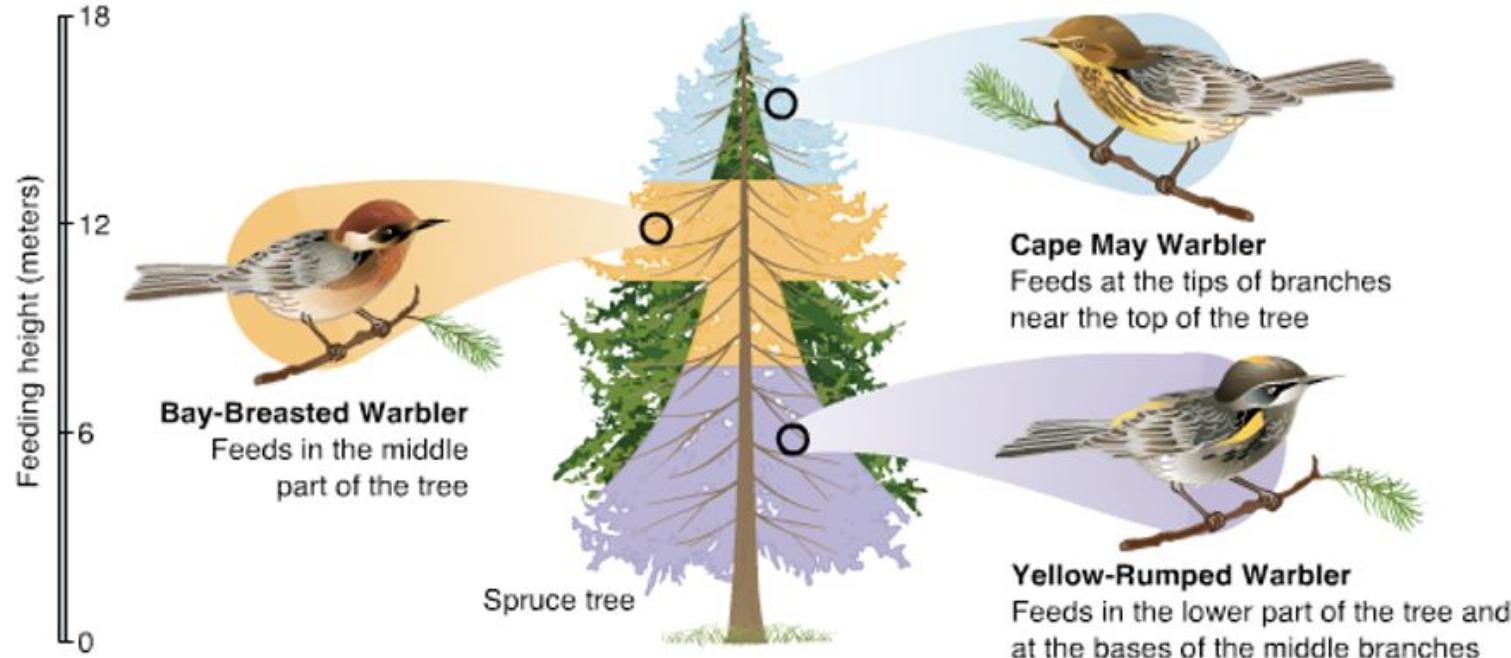
inputs  
molecular structure



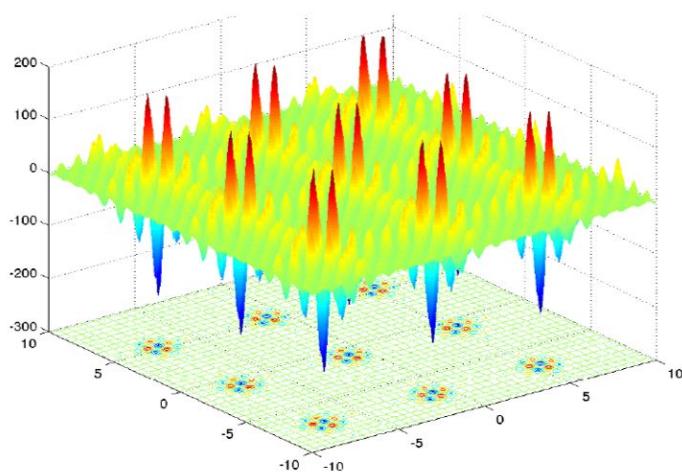
outputs



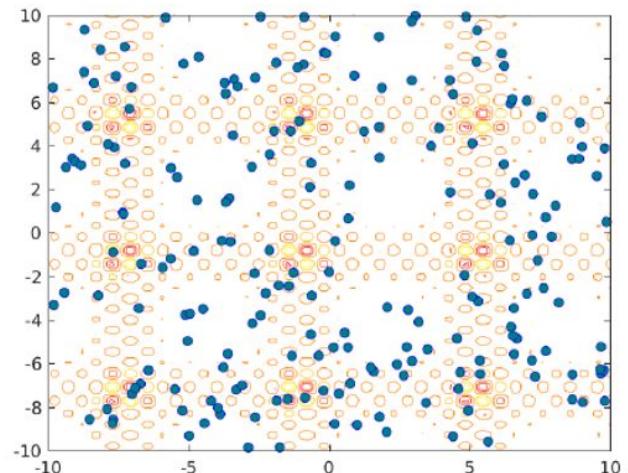
# niching methods



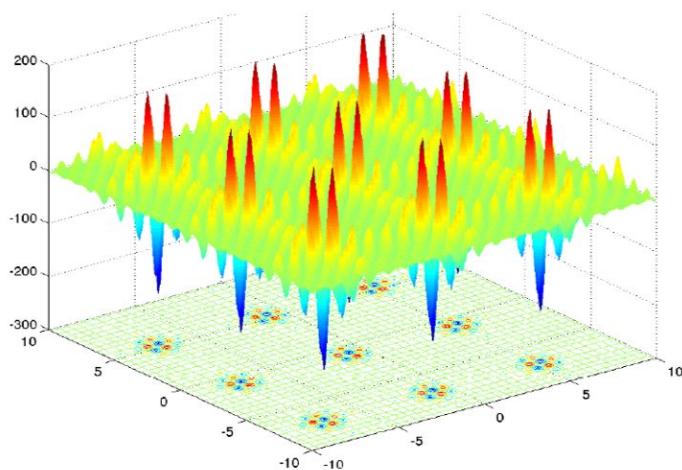
# niching methods



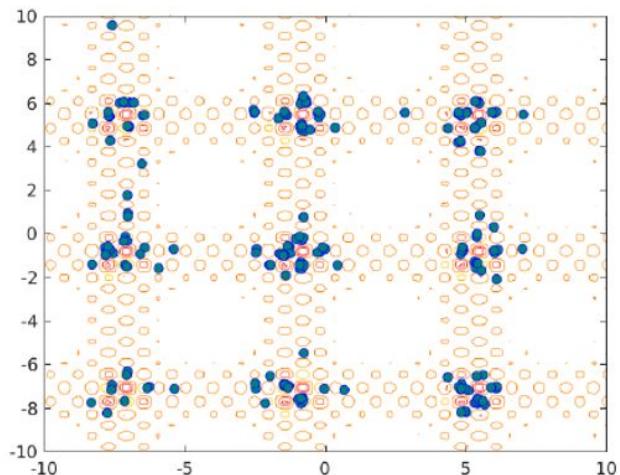
0th  
generation



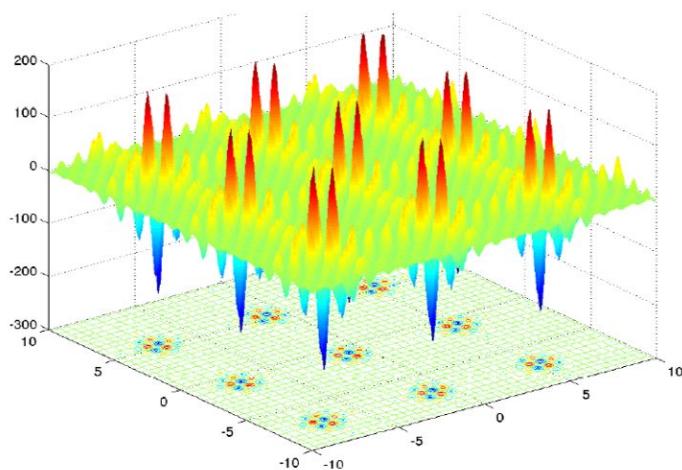
# niching methods



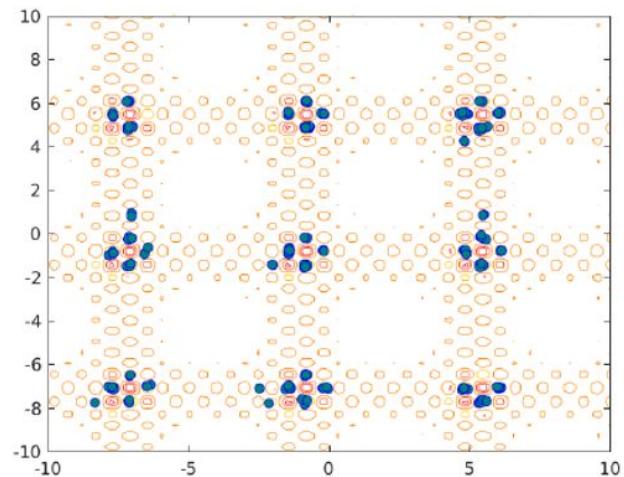
50th  
generation



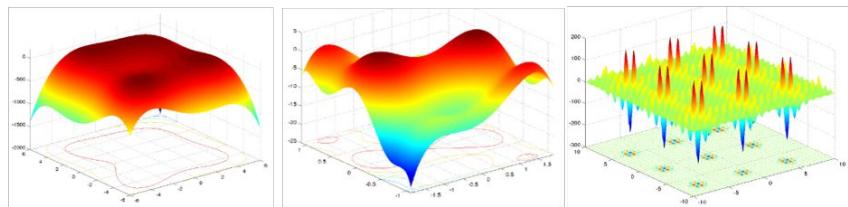
# niching methods



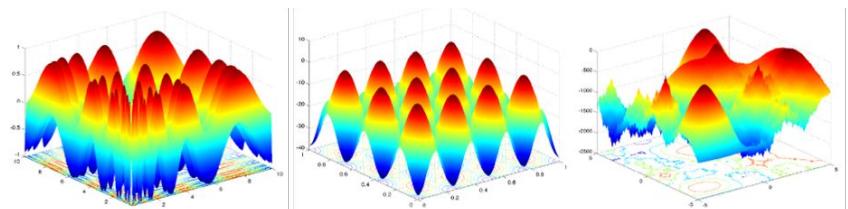
100th  
generation



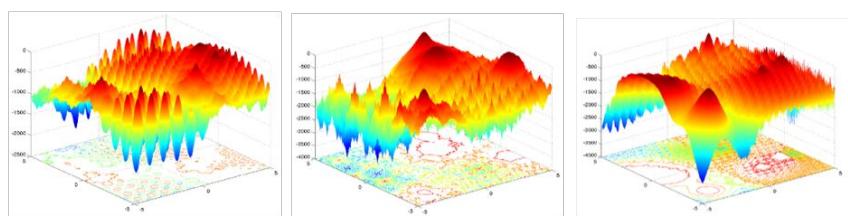
DE/nrand/1/bin



Crowding DE/rand/1/bin



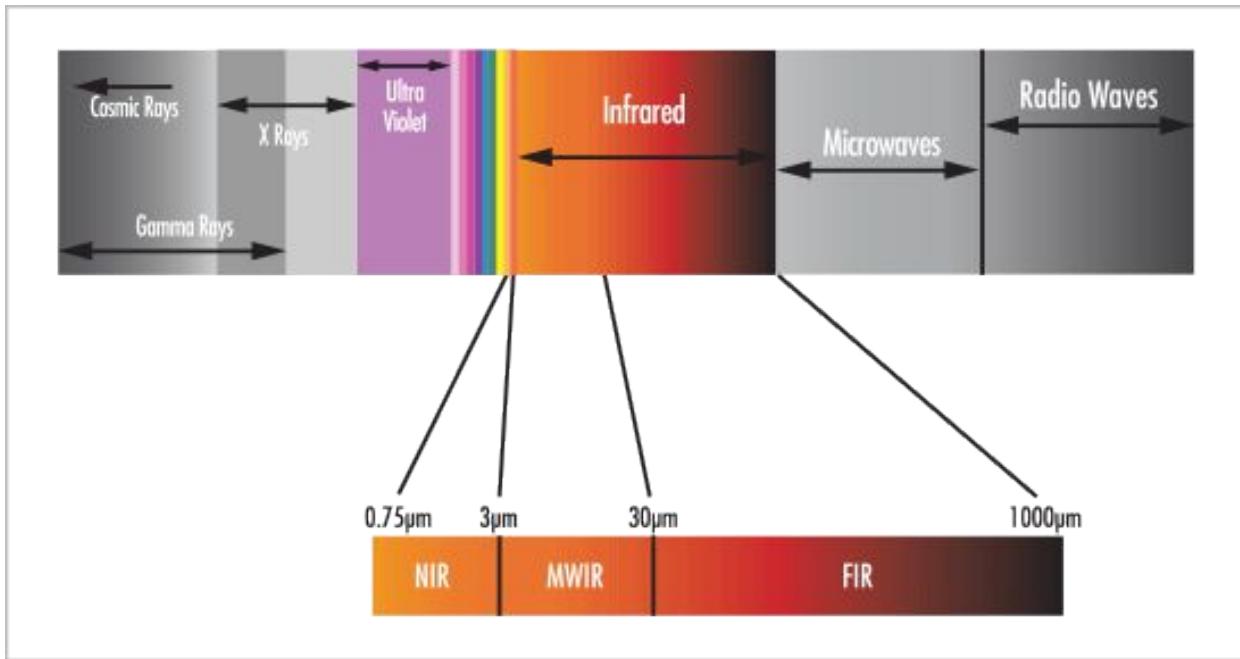
IEEE WORLD CONGRESS ON  
COMPUTATIONAL INTELLIGENCE  
8-13 July 2018, Rio de Janeiro, Brazil



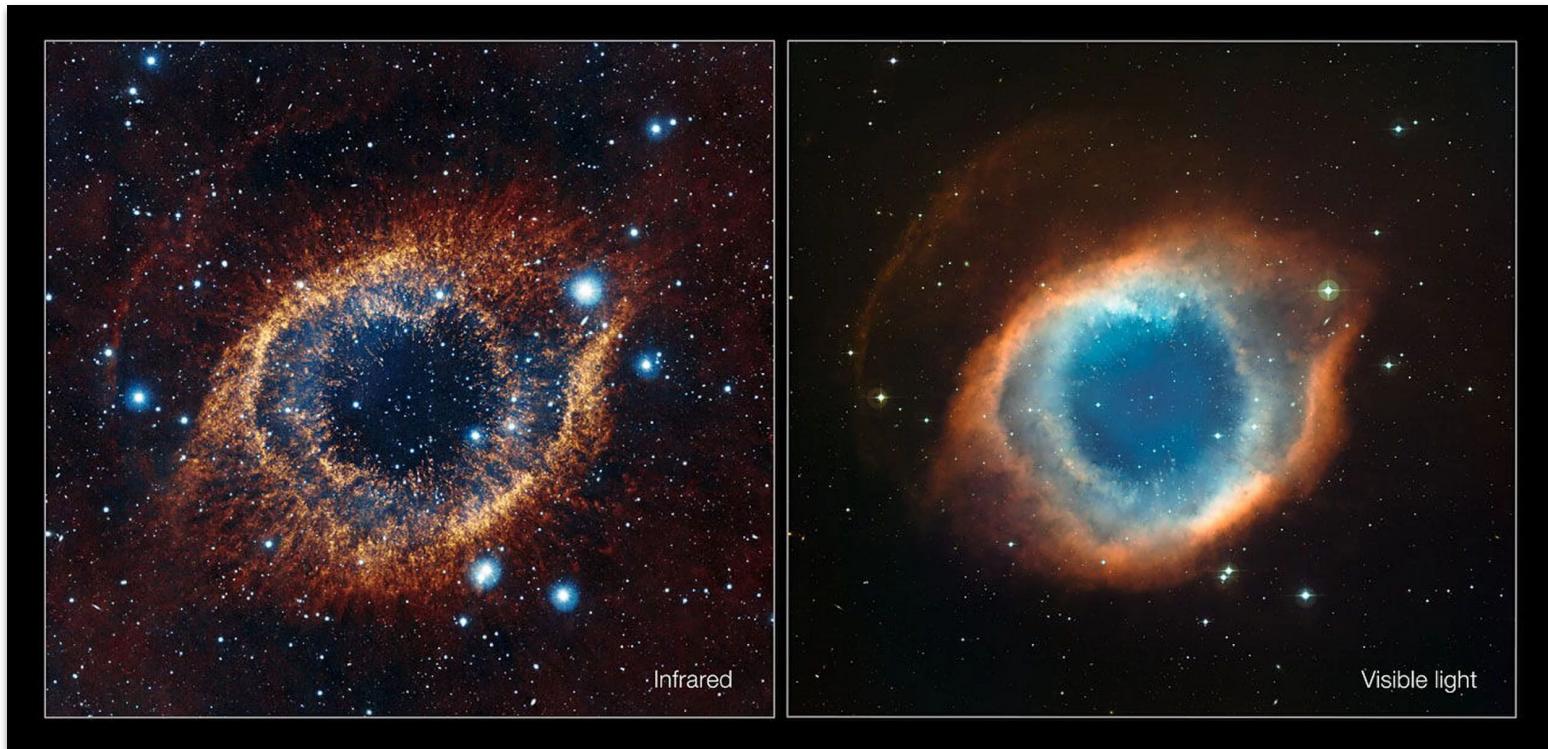


optimization of quantum well  
infrared photodetectors

# infrared radiation



Helix Nebula acquired with the VISTA telescope in infrared light (left) and the more familiar view in visible light from the MPG/ESO 2.2-metre telescope (right).

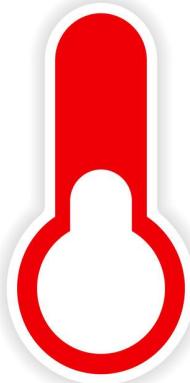




Credit: UTC Aerospace Systems, Princeton, NJ, USA



infrared radiation  
- detectors -



thermal detectors



photodetectors

# infrared radiation

## - detectors -

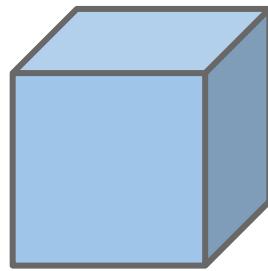


photodetectors

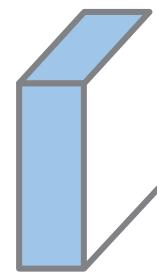
- Bulk - HgCdTe
- Nanostructured materials
  - ◆ Quantum Dots (QDIPs)
  - ◆ Quantum Wells (QWIP)

# infrared radiation

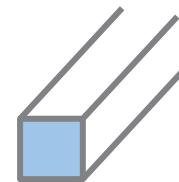
- nanostructured materials -



bulk



quantum  
well



quantum  
wire

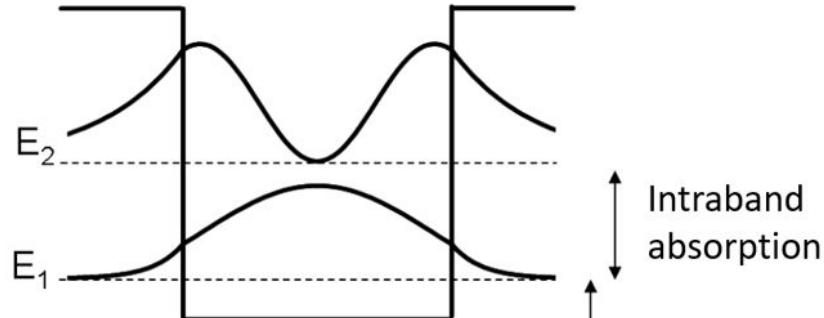


quantum  
dot

# quantum well infrared photodetectors (QWIPs)



Conduction band

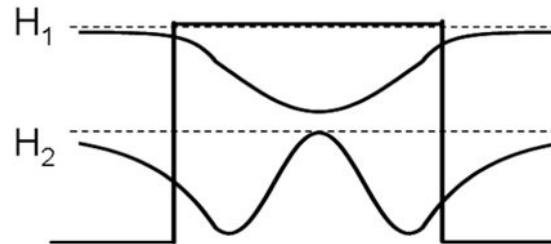


Intraband  
absorption

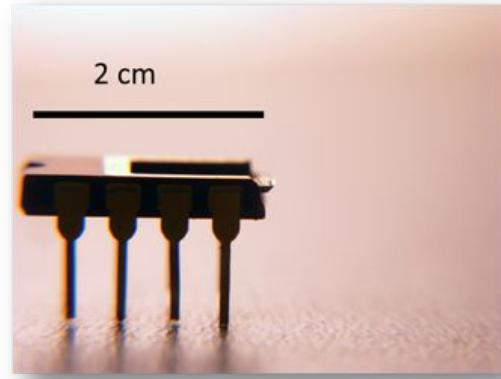
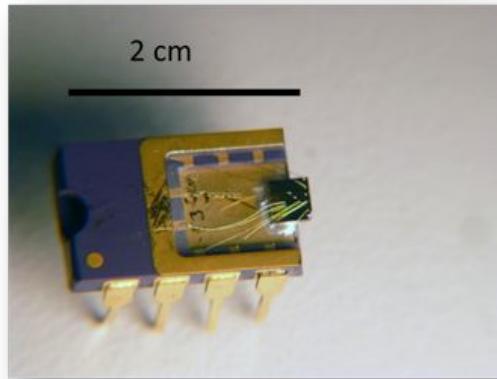
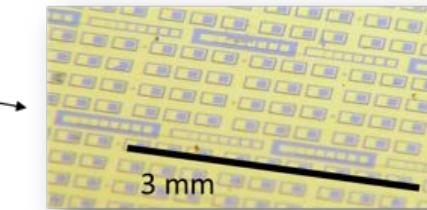
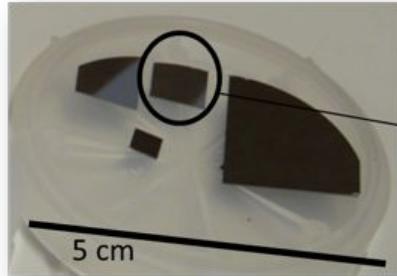
Interband  
absorption

Intraband  
absorption

Valence band

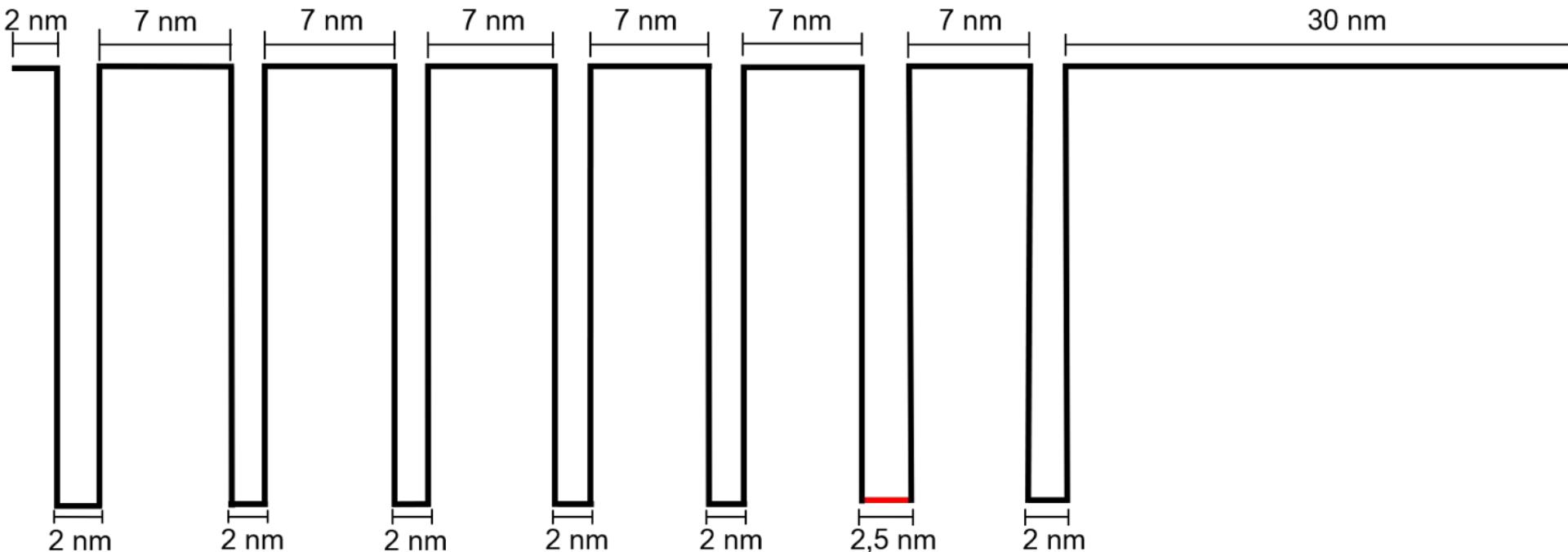


# quantum well infrared photodetectors (QWIPs)



# quantum well infrared photodetectors (QWIPs)

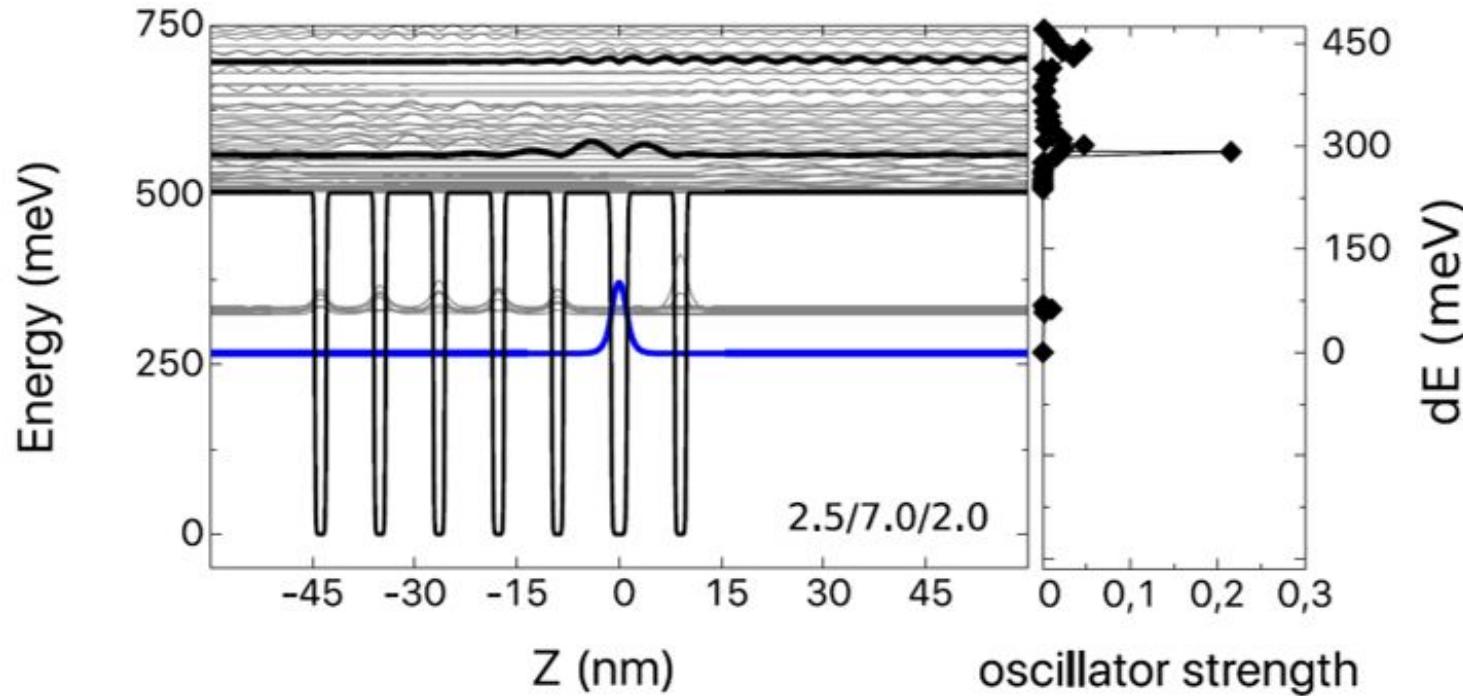
Asymmetric InGaAs/InAlAs superlattice.



PENELLO, G. M.; PEREIRA, P. H.; PIRES, M. P.; SIVCO, D.; GMACHL, C.; SOUZA, P. L.. Leaky electronic states for photovoltaic photodetectors based on asymmetric superlattices. *Applied Physics Letters*, 112(3):033503, 2018.

# quantum well infrared photodetectors (QWIPs)

Asymmetric InGaAs/InAlAs superlattice.



# optimization of QWIPs

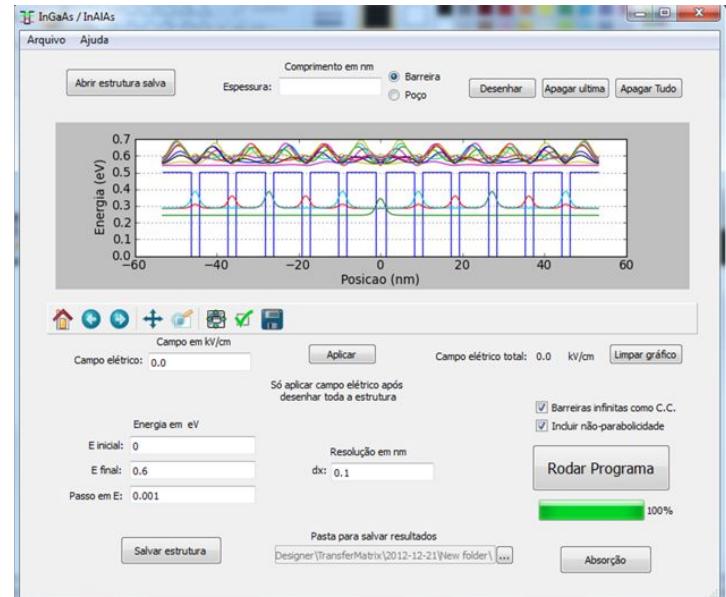


MG-PMA

GA

PSO

CMA-ES



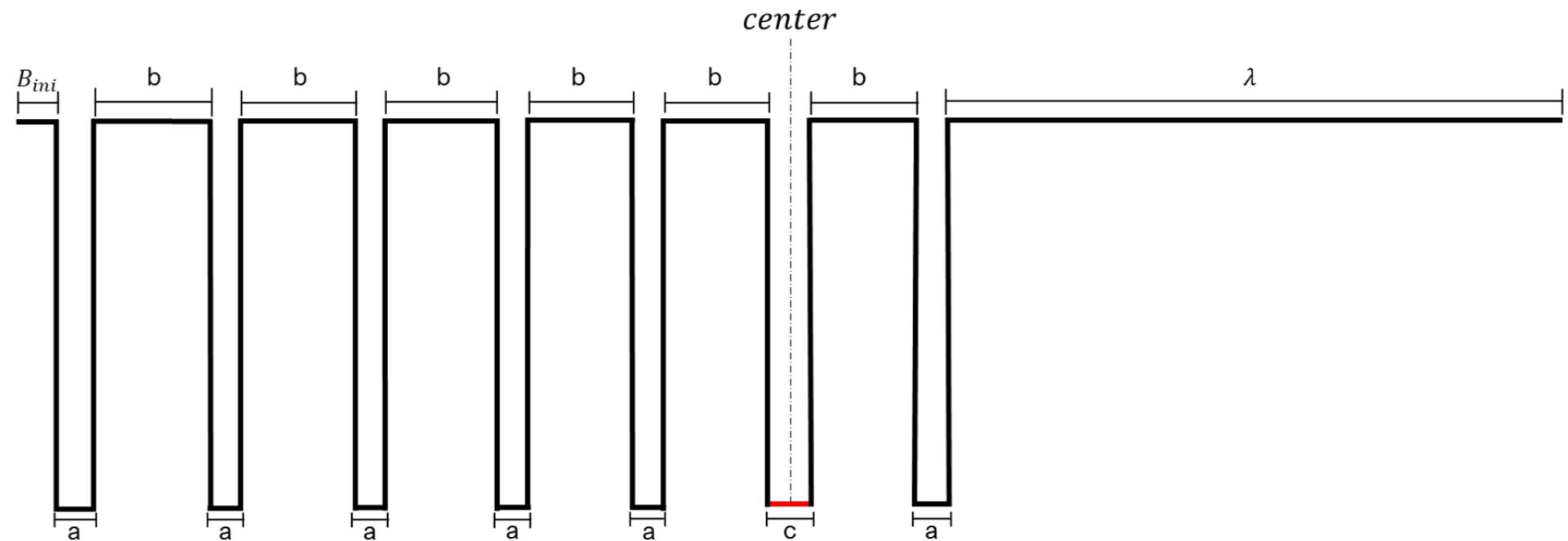
# optimization of QWIPs



Thicknesses to be optimized: **a**, **b** and **c**.

$$center = B_{ini} + 5a + 5b + \frac{c}{2}$$

$$\lambda = center - \frac{c}{2} - a - b$$



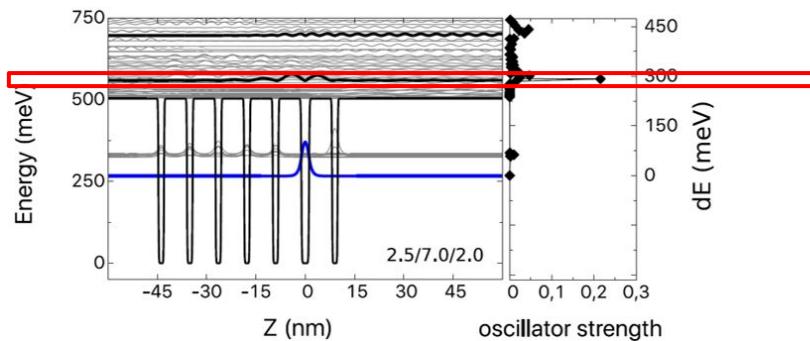
# optimization of QWIPs

## - objective function -



$$f_{0d} = \frac{2m^*}{\hbar} (E_d - E_0) |M_{0d}|^2$$

$$|M_{0d}|^2 = \left| \int_{-\infty}^{+\infty} \psi^*(z) (-ez) \psi(z) dz \right|^2$$



energy range: [295, 305] meV

# optimization of QWIPs

## - results -

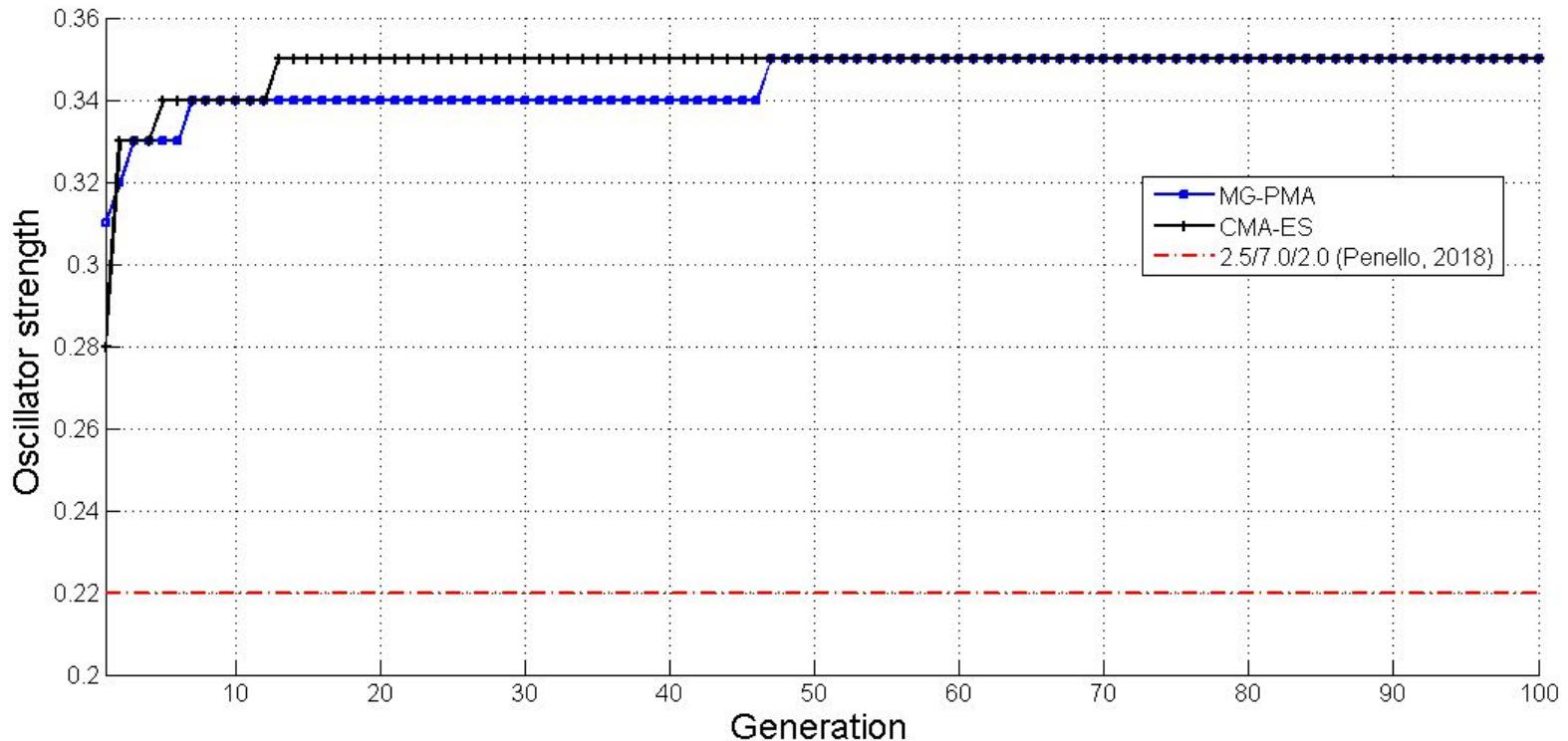


**Oscillator strength of the initial structural:** 0.22

Method	Max	Mean	Min	Std
MG-PMA	<b>0.35</b>	<b>0.35</b>	0.34	9.99e-4
GA	<b>0.35</b>	0.34	0.34	3.42e-3
PSO	<b>0.35</b>	<b>0.35</b>	<b>0.35</b>	7.07e-5
CMA-ES	<b>0.35</b>	<b>0.35</b>	<b>0.35</b>	<b>1.01e-6</b>

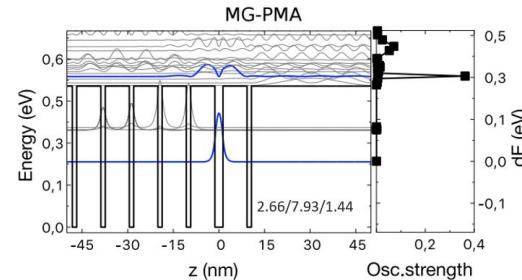
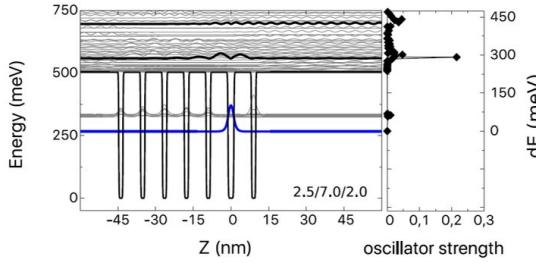
# optimization of QWIPs

## - results -

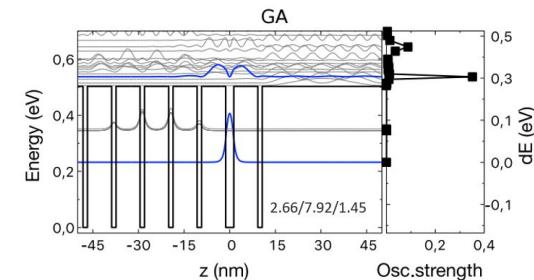


# optimization of QWIPs

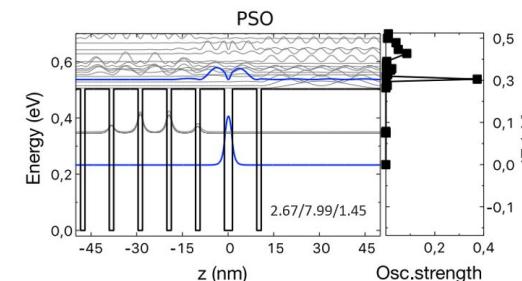
## - results -



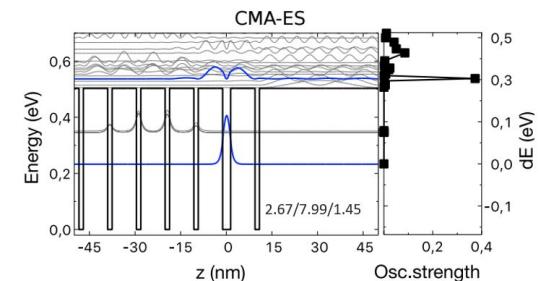
**2.66/7.93/1.44**



**2.66/7.92/1.45**



**2.67/7.99/1.45**

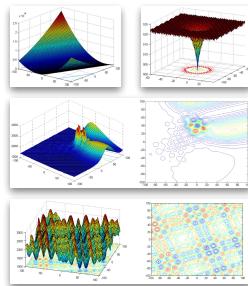


**2.67/7.99/1.45**

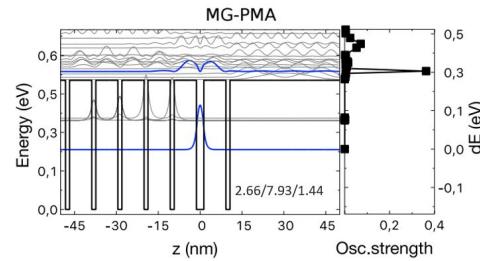
# Development of unimodal and multimodal optimization algorithms based on multi-gene genetic programming



OGP



benchmark  
functions



real  
problem

# Development of unimodal and multimodal optimization algorithms based on multi-gene genetic programming

Evolutionary Computation

Genetic Programming

Multi-Gene Genetic Programming

High-Level Crossover Operators

Optimization by Genetic Programming

Multimodal Optimization

Niching Methods

Clearing

Niching Methods for Metaheuristic Optimization Algorithms

Multi-Gene Parameter Mapping Approach

Multi-Gene Parameter Mapping Approach with Feedback

Niching Multi-Gene Parameter Mapping Approach

Domain Constraint with Periodic Boundary Conditions

Analyses of Multigenic Individuals

Analysis of Tournament Size and Crossover

Comparison with Known Methods

Analysis of High-Level Crossover Operator

Analysis of Local Optimization Frequency

Analysis of Feedback Frequency

Nonparametric Statistical Analyses

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